

# Upper bounds on signals due to WIMP self-annihilation: comments on the case of the synchrotron radiation from the galactic center and the WMAP haze

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Two recent papers reconsider the possibility that the excess of microwave emission from a region within  $\sim 20^\circ$  of the galactic center (the *WMAP haze*), measured by WMAP, can be due to the synchrotron emission originated by neutralino self-annihilation; on the basis of this possible occurrence, also upper bounds on the neutralino self-annihilation cross-section are suggested. In the present note, we show that in the common case of thermal WIMPs in a standard cosmological model, when the rescaling of the galactic WIMP density is duly taken into account for subdominant WIMPs, the upper bound applicable generically to *any* signal due to self-conjugate WIMPs is more stringent than the ones obtained from analysis of the WMAP haze. We also argue that an experimental upper bound, which can compete with our generic upper limit, can rather be derived from measurements of cosmic antiproton fluxes, for some values of the parameters of the astrophysical propagation model. Finally, we comment on the possible impact of our generic upper bound on the interpretation of the WMAP haze in terms of thermal neutralinos in a standard cosmological scheme.

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Synchrotron radiation, emitted by positrons and electrons created by self-annihilation of WIMPs in the galactic center, has long since been analyzed as a potentially interesting signature for particle dark matter in our Galaxy. In Refs. [1, 2] it has been suggested that the synchrotron emission due to WIMPs can also be responsible for an excess of microwave emission from a region within  $\sim 20^\circ$  of the galactic center (the *WMAP haze*), measured by WMAP [3]. In Ref. [4] this possible connection of the WMAP haze with WIMP annihilation in the galactic center has been reconsidered, with the purpose of putting upper bounds on the neutralino self-annihilation cross-section. The analysis of Ref. [4] is carried out in terms of various annihilation channels and dark matter density profiles.

In the present note we address some of the previous aspects in the usual framework of thermal WIMPs in a standard cosmological model. First we recall that a generic upper bound for indirect signals due to self-interaction of *any* thermal self-conjugate WIMP can be derived in a model-independent way. Then we show that an experimental upper bound which can compete with the generic upper limit and is conservatively stronger than the one obtained from the WMAP haze is derivable from measurements of cosmic antiproton fluxes, for some values of the parameters of the astrophysical propagation model. Finally, we discuss the relevance of the generic upper limit for an interpretation of the WMAP

haze in terms of neutralino self-annihilation in the galactic center. In what follows, we use the subscript  $\chi$  to denote properties related to our generic self-conjugate WIMP (not necessarily a neutralino).

The first point was discussed in Refs. [5, 6] and further developed in Ref. [7]. The reasoning goes as follows. Any signal due to WIMP self-annihilation is proportional to  $\rho_\chi^2(\vec{r})\langle\sigma_{\text{ann}}v\rangle_0$ , where  $\rho(\vec{r})_\chi$  is the WIMP galactic distribution and  $\langle\sigma_{\text{ann}}v\rangle_0$  is the average, over the Galactic velocity distribution, of the WIMP annihilation cross-section multiplied by the relative velocity. For convenience, we rewrite  $\rho(\vec{r})_\chi$  as  $\rho(\vec{r})_\chi = \rho(\vec{r})\xi$ , where  $\rho(\vec{r})$  denotes the total dark matter galactic distribution and  $\xi$  the fractional part due to the WIMP  $\chi$ . Thus, the signal depends on the specific physical properties of  $\chi$  through the quantity  $\xi^2\langle\sigma_{\text{ann}}v\rangle_0$ , and not simply through  $\langle\sigma_{\text{ann}}v\rangle_0$ .

This is a crucial point, which can be elucidated by employing the rescaling recipe of Ref. [8] for obtaining the factor  $\xi$ , *i.e.* by setting  $\xi = \min[1, \Omega_\chi h^2 / (\Omega_{\text{CDM}} h^2)_{\text{min}}]$ , where  $(\Omega_{\text{CDM}} h^2)_{\text{min}}$  is the minimal amount of cold dark matter in the Universe. We recall that this factor  $\xi$  has the effect of rescaling the WIMP galactic density, when its average relic density in the Universe is below the minimal amount required for cold dark matter on the basis of cosmological observations (in other words, when the generic candidate  $\chi$  represents only a subdominant component of cold dark matter).

Once the factor  $\xi$  is introduced by the rescaling recipe of Ref. [8], one can readily understand some relevant properties of  $\xi^2 \langle \sigma_{\text{ann}} v \rangle_0$  as a function of the set  $\eta$  of parameters of the particle physics model which describes our generic cold relic. Taking into account the relations among the annihilation cross-section at zero temperature  $\langle \sigma_{\text{ann}} v \rangle_0$  (relevant to the WIMP signal), the integral of  $\langle \sigma_{\text{ann}} v \rangle_{\text{FO}}$  from the present temperature up to the freeze-out temperature  $T_f$  (relevant to the relic abundance) and the WIMP relic abundance  $\Omega_\chi h^2$ , by analytic arguments one derives that the quantity  $\xi^2 \langle \sigma_{\text{ann}} v \rangle_0$  has a maximum, *independent* of  $m_\chi$ . This maximum is given by:  $(\xi^2 \langle \sigma_{\text{ann}} v \rangle_0)_{\text{max}} = \langle \sigma_{\text{ann}} v \rangle_0|_{\eta=\eta'}$ , where the values  $\eta'$  are such that  $(\Omega_\chi h^2)_{\eta=\eta'} = (\Omega_{\text{CDM}} h^2)_{\text{min}}$  (see Ref. [7] for the details of the derivation). We disregard here special situations such as the one where co-annihilation would play a relevant role.

An estimate for  $(\xi^2 \langle \sigma_{\text{ann}} v \rangle_0)_{\text{max}}$  can be derived analytically, if one employs the standard expansion in S and P waves:  $\langle \sigma_{\text{ann}} v \rangle \simeq \tilde{a} + \tilde{b}/x$ , for the thermally averaged product of the annihilation cross-section times the relative velocity of the self-interacting particles ( $x = m_\chi/T$  where  $T$  is the temperature of the Universe), assuming that  $\tilde{a} \geq |\tilde{b}|/(2x_f)$  and that no substantial cancellations occur between the S and P terms (*i.e.*  $\tilde{a} \gg |\tilde{b}|/(2x_f)$ ), in case of negative values of  $\tilde{b}$  ( $x_f$  is the value of  $x$  at freeze-out).

By plugging in numbers (an important ingredient being the WMAP value  $(\Omega_{\text{CDM}} h^2)_{\text{min}} = 0.092$ ), one obtains [7]  $(\xi^2 \langle \sigma_{\text{ann}} v \rangle_0)_{\text{max}} \simeq 3 - 5 \times 10^{-26} \text{ cm}^3 \cdot \text{s}^{-1}$  independently of  $m_\chi$ . This result, valid for a generic WIMP, is supported and strengthened by numerical analysis, in the case of relic neutralinos (see Fig. 2 of Ref. [7]), to:

$$(\xi^2 \langle \sigma_{\text{ann}} v \rangle_0)_{\text{max}} \simeq 3 \times 10^{-26} \text{ cm}^3 \cdot \text{s}^{-1}. \quad (1)$$

Notice that, whereas the quantity  $\xi^2 \langle \sigma_{\text{ann}} v \rangle_0$  is limited from above by the bound of Eq. (1), the quantity  $\langle \sigma_{\text{ann}} v \rangle_0$  is limited from below, since the cosmological bound  $\Omega_\chi h^2 \leq (\Omega_{\text{CDM}} h^2)_{\text{max}} \simeq 0.12$  implies  $\langle \sigma_{\text{ann}} v \rangle_0 \gtrsim 9 \times 10^{-27} \text{ cm}^3 \cdot \text{s}^{-1}$ . However, for instance in the case of neutralinos,  $\langle \sigma_{\text{ann}} v \rangle_0$  can take values much larger than its lower bound in sizable regions of the supersymmetric parameter space, though obviously preserving the upper limit of  $\xi^2 \langle \sigma_{\text{ann}} v \rangle_0$ . Upper limits on  $\langle \sigma_{\text{ann}} v \rangle_0$  are only related to the particle physics properties of the WIMP candidate, and constrained by accelerator data and other laboratory precision measurement.

Now we turn to the comparison of our bound of Eq. (1) with the ones presented in Ref. [4]. Notice that the analysis carried out in Ref. [4] concerns WIMPs largely contributing to the galactic dark matter in a framework which includes non-thermal production or in general non-standard cosmology. The upper bounds derived in Ref.

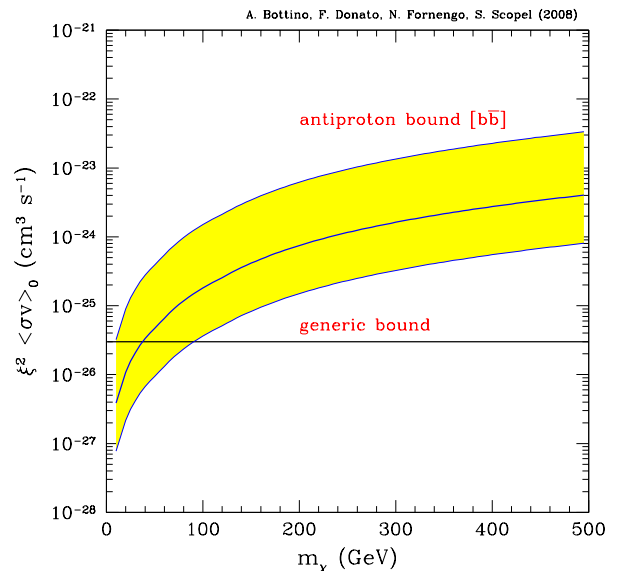


FIG. 1: Generic upper bound of Eq.(1) (horizontal solid line) and bounds from cosmic antiproton searches (shaded area) for the quantity  $\xi^2 \langle \sigma_{\text{ann}} v \rangle_0$ . The generic upper bound applies to thermal WIMPs. The antiproton bound is derived for the case of WIMP annihilation into a  $b\bar{b}$  final state [10] and defined as the admissible excess in the available data [11] (for antiprotons kinetic energy of 0.23 GeV) over the standard background [12] at  $2\sigma$ . The upper, median and lower lines refer to the maximal, median and minimal fluxes obtained by varying the diffusion models parameters.

[4] can be immediately converted into upper bounds in the scheme we are discussing here (thermal WIMPs in a standard cosmological model) by simply substituting the quantity  $\langle \sigma_{\text{ann}} v \rangle_0$  on the vertical axis of Fig. 3 of Ref. [4] by the quantity  $\xi^2 \langle \sigma_{\text{ann}} v \rangle_0$ .

Thus, we find that in the standard case of a thermal WIMP, the generic upper bound of Eq. (1), based only on rescaling properties and the low-energy expansion, is more stringent than those derived in Ref. [4], which imply a number of specific astrophysical and particle-physics hypotheses. The upper bounds of Ref. [4] approach the upper limit of Eq. (1) only in a narrow window with neutralinos masses  $\sim 100$  GeV, when a Navarro-Frenk-White halo profile is assumed. For a less steep density distribution, like in the case of a cored profile, Ref. [4] shows that the bound obtained from the synchrotron emission is significantly milder.

It is also worth noting that, as far as neutralinos are concerned, the bound  $(\xi^2 \langle \sigma_{\text{ann}} v \rangle_0)_{\text{max}} \simeq 3 \times 10^{-26} \text{ cm}^3 \cdot \text{s}^{-1}$  is certainly more stringent than the ones derivable by

present measurements of the cosmic positron spectrum and by the EGRET gamma ray spectrum. This simply because in these two cases the signals originated by neutralino annihilation require anyway a robust boost factor in order to fit the experimental data. Instead, for cosmic antiprotons, available experimental data can disallow a number of supersymmetric configurations for some values of the parameters of the astrophysical diffusion model [9]. Note that this is at variance with what stated in Ref. [4], where the constraints from antiprotons are not considered and it is affirmed that the bound from synchrotron emission is more stringent than that provided by any other current indirect detection channel. As an example of the bound which can be obtained from the antiproton signal, we show in Fig. 1 the upper limit on  $\xi^2 \langle \sigma_{\text{ann}} v \rangle_0$  obtained by considering the antiproton flux from dark matter annihilation at kinetic energy  $T_{\bar{p}} = 0.23$  GeV [10] and comparing it with the current available data [11] and background determination [12]. In Fig. 1 we have considered the uncertainty in the calculation of the antiproton flux which originates from the galactic propagation. For masses below 100 GeV and for a wide range of the astrophysical parameters involved in the diffusion process, antiproton searches can set limits stronger than the generic bound of Eq. (1). In a more refined analysis, which takes into account the whole antiprotons energy spectrum, the upper bound of Eq. (1) has been employed in Ref. [7] to establish that, in absence of a substantial clumpiness effect in the Galaxy [13], the cosmic antiproton spectrum is expected to be insensitive to neutralino annihilation for neutralino masses  $\gtrsim 200$  GeV.

Finally, we turn to some comments about the impact that our upper bound in Eq. (1) can have on the interpretation of the WMAP haze in terms of thermal WIMPs.

For this purpose a useful guide is provided by the lower frame of Fig. 3 in Ref. [2], where a density profile steeper than the NFW is adopted. Firstly, by comparing the results there reported with the bounds derived in Ref. [4], one realizes that large astrophysical and particle physics uncertainties affect the evaluation of the haze effect. If we now wish to extract from the results of Ref. [2] the relevant thermal WIMP candidates, we have to limit the values of  $\langle \sigma_{\text{ann}} v \rangle_0$  from below, since the cosmological upper bound implies  $\langle \sigma_{\text{ann}} v \rangle_0 \gtrsim 9 \times 10^{-27} \text{ cm}^3 \cdot \text{s}^{-1}$ . Taking into account the bound of Eq. (1), one finds that, for most of the annihilation modes, an interpretation of the WMAP haze in terms of thermal WIMPs constituting the most part of dark matter favors relics with a mass  $m_\chi \lesssim 400$  GeV. In the case of a direct annihilation into  $e^+ - e^-$ , larger values of the WIMP mass are accessible.

To better constrain the model in terms of thermal (dominant or subdominant) neutralinos, it would be interesting to carry out a detailed combined analysis of cosmic antiproton fluxes and of the WMAP haze effect, using, for both type of signals, the same diffusion model and density profile.

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- [1] D.P. Finkbeiner, arXiv:astro-ph/0409027.
  - [2] D. Hooper, D.P. Finkbeiner and G. Dobler, arXiv:0705.3655 (astro-ph).
  - [3] D.N. Spergel *et al.* (WMAP Collaboration), *Astrophys. J. Suppl.* **148**, 175 (2003); *ibidem* **170**, 263 (2007).
  - [4] D. Hooper, arXiv:0801.4378 (astro-ph).
  - [5] A. Bottino, C. Favero, N. Fornengo, G. Mignola and S. Scopel, *Proc. of the International Workshop "Double-beta Decay and Related Topics"* (Ed. H.V. Klapdor-Kleingrothaus and S. Stoica, ECT\*/Trento, 1995), 281 (World Scientific, 1996).
  - [6] A. Bottino, F. Donato, N. Fornengo and S. Scopel, *Proc. of "Results and Perspectives in Particle Physics"*, (Ed. M. Greco, La Thuile, 2001) 135 (INFN Laboratori Nazionali Frascati) [hep-ph/0105233].
  - [7] A. Bottino, F. Donato, N. Fornengo and P. Salati, *Phys. Rev. D* **72**, 083518 (2005).
  - [8] T.K. Gaisser, G. Steigman and S. Tilav, *Phys. Rev. D* **34**, 2206 (1986).
  - [9] A. Bottino, F. Donato, N. Fornengo and S. Scopel, *Phys. Rev. D* **70**, 015005 (2004).
  - [10] F. Donato, N. Fornengo, D. Maurin, P. Salati and R. Taillet *Phys. Rev. D* **69** (2004) 063501.
  - [11] S. Orito *et al.* (BESS Collaboration), *Phys. Rev. Lett.* **84** (2000) 1078; T. Maeno *et al.* (BESS Collaboration), *Astropart. Phys.* **16** (2001) 121; M Aguilar *et al.* (AMS Collaboration), *Phys. Rep.* **366** (2002) 331.
  - [12] F. Donato *et al.*, *Astrophys. J.* **563** (2001) 172.
  - [13] Large values for the boost factor are unlikely, see: V. Berezhinsky, V. Dokuchaev and Y. Eroshenko, *Phys. Rev. D* **68**, 10303 (2003); J. Lavalle, Q. Yuan, D. Maurin and X.J. Bi, arXiv:0709.3634 [astro-ph].